ON THE STUDY OF EARTHQUAKES IN GREAT BRITAIN.[1]

THERE can be little doubt that the more important contributions to our knowledge of earthquakes must be made in countries like Switzerland, Italy, and Japan ; countries where earthquakes are frequently occurring, where, occasionally, they are so disastrous as to arrest universal attention, and where, at the same time, there are many skilled observers aided by a sympathetic and intelligent public. In England, as every strong shock shows, there is no lack of observers. But our earthquakes that are strong enough to attract general notice within the disturbed area are few and far between. If we exclude special districts, like Comrie and the Durham coast, we shall probably be well within the mark in stating the average number recorded as less than one a month.

The number of earthquakes that occur in Great Britain must, however, be far greater than this. From various causes, many shocks that are felt are never placed on record. Others, again, that might be felt, must certainly pass unnoticed, for, wherever seismic studies are newly organized, it is found that people become educated in detecting earthquake-shocks. But, however skilful observers may become, there must always be a large number of shocks that never could be felt, either from the small amplitude or the long period of their vibrations. Even in Tokio, where they talk about earthquakes as we in England talk about the weather, "the majority of shocks pass unfelt by people, while seismographs register them sufficiently to allow measurements" (S. Sekiya, Japan Seism. Soc. Trans., vol. x. p. 59).

There is every reason to conclude, then, that, with the aid of simple time-recording seismoscopes, the earthquakes of Great Britain would be found sufficiently numerous to repay a more careful and systematic study. That we shall have to be content, as a rule, with observing shocks that would elsewhere be considered slight is evident of course ; but in their very feebleness we possess advantages which are not afforded by severer shocks of other lands. Not only are the phenomena much less complex ; but, not being unnerved by danger, the observer is able to concentrate his attention on them more calmly and completely. Still more important is the fact, and in this lies their greatest value, that, the smaller the area disturbed, the more nearly can the position of the epicentrum be determined. If, as is frequently the case, the shock be felt only within a small circular area, we cannot be far wrong in regarding the centre of that area as the approximate site of the epicentrum. And thus we easily obtain the solution of what, in a great earthquake, is one of the most difficult and important of the problems to be attacked.

Methods of Study in Great Britain.—Owing to the feebleness of our shocks, and their comparative rarity in a given district, the methods of study employed by us must clearly be different from, and inferior to, those adopted with such signal success in Italy and Japan. We can hardly expect, for instance, that costly recording instruments will be widely used in this country ; for, even in Italy, as Prof. de Rossi points out (*Bull. del Vulc. ital.*, anno iv., 1877, p. 5), it has been found better to have a large number of observatories containing cheap and simple instruments, than a few equipped with seismographs more perfect and refined.

If, on the one hand, then, our methods of earthquake study are limited by the nature of the shocks we experience, on the other we possess advantages, apart from those already mentioned, that are more or less wanting in regions where the phenomenon attains a more destructive and interesting development. For instance, most parts of England at any rate are so densely populated that we are able, almost wherever a shock occurs, to procure a large number of observations of very considerable value. And again, in the ease and accuracy with which we can regulate our clocks in the neighbourhood of every large town, we have an aid in our work which is as valuable as it is rare in foreign countries. These two facts in particular I mention here because they form the foundation of our two most promising methods of investigation.

Looking at earthquakes chiefly from a geological point of view—that is, regarding them as mere incidents, but at the same time delicate indices, of the progress of terrestrial evolution—the prime object of our inquiries is in every case to determine the position of the epicentrum, and, if possible, that of the seismic focus. For this purpose, we have three methods at our disposal, depending severally upon observations of the direction, intensity, and time of occurrence, of the shock in different parts of the disturbed area.

The first method is interesting historically from its having been used by Mallet in the earliest scientific study of an earthquake. But modern seismologists have with good reason generally discarded it ; and, in any case, it could hardly be employed with success in this country.

The method of intensities is far more trustworthy, and is attended with good results whenever the observations are sufficiently numerous and made at places that are fairly evenly distributed over the disturbed area. With the aid of such a scale as that drawn up by MM. de Rossi and Forel, the intensity of the shock at any point may be roughly estimated. Then, drawing lines including all places where the intensity is at or above a certain degree of the scale, we obtain a series of lines of equal intensity (isoseismal lines), which, closing in towards the epicentrum, enable its position to be approximately determined. For the slighter shocks that we experience, it would be difficult to over-estimate the value of this method, the only one that in certain cases can be applied.

The last of the three methods, I think I may say, is still upon its trial ; and if, so far, it has not yielded all the results that are to be expected from it, I believe the reason is that it has not yet been attempted in a country where the conditions are so favourable for its application as they are in many parts of England. What we require for the purpose is, not a network of time-recording instruments extending over the whole country, so much as a moderate number suitably placed and regularly observed in specially selected districts. If, by means of these instruments or otherwise, the times of a shock can be ascertained with accuracy at five or more places, these, under certain conditions, are theoretically sufficient to determine the position of the epicentrum, the depth of the seismic forces, the velocity of the earth-wave, and, consequently, the time of occurrence at the focus. And it should be noticed that time-recorders in Great Britain are practically free from the objection which attends them in Japan and other regions where earthquakes frequently last for one or several minutes. For, in such cases, the character of the shock varies so greatly throughout the disturbed area, that it need not, and probably will not, be one and the same vibration which is registered in different places, and considerable errors may thus be introduced.[1] If, then, we remember that our earthquake shocks seldom last for more than a few seconds at most, and that, in many parts of England and some parts of Scotland, it should be possible to ascertain the time of occurrence correctly to within a small fraction of a minute, I think there can be little doubt that, for all but the slightest shocks, a most fruitful method of earthquake study in this country would be a system for securing accurate time-records whenever a shock is felt.

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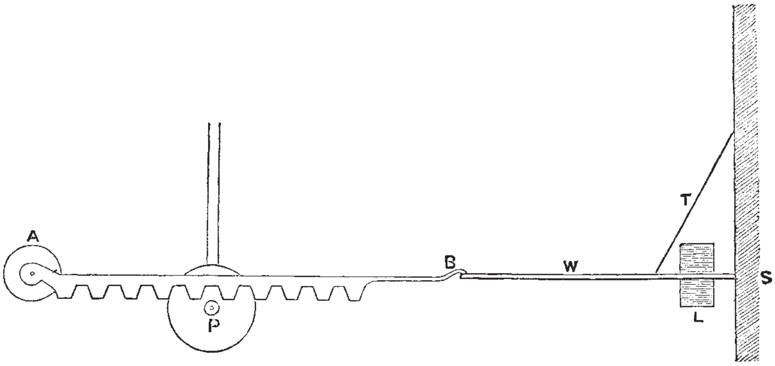
[1] A Paper by Charles Davison, M.A., King Edward's High School, Birmingham; read before the Birmingham Philosophical Society on February 5, 1890. A few passages added since the paper was read are enclosed in brackets.

[1] E. Knipping and H. M. Paul, Japan Seism. Soc. Trans., vol. vi. p. 37 ; also J. A. Ewing, vol. iii. pp. 63–64, and J. Milne, vol. iv. pp. 100–101.

Seismoscopes.—A large number of simple and inexpensive seismoscopes have been devised and used for recording the time of occurrence of an earthquake shock; but it is difficult to find one that in all respects is thoroughly satisfactory.[1] To be so, they should fulfil the following conditions:—They should be inexpensive, simple in their construction, easy to arrange, and require little attention when once erected. They should record the occurrence of shocks and tremors with equal facility in whatever direction they may arrive; and they should be equally sensible in recording a feeble shock. It is very desirable also that they should be of similar construction, at any rate in a given district, if not throughout the whole country, so that observations from different places may be rightly comparable.

Again, in countries where earthquakes are frequent, and where the shocks may succeed one another at short intervals, it is important that the record should be made without stopping the clock. In Great Britain, however, our catalogues show that, except at Comrie, it is not usual for sensible earthquakes to follow one another rapidly, and it is therefore worth while considering whether, on account of their much greater cheapness and simplicity, it might not be well to avail ourselves in this country of clock-stopping apparatus. Such instruments, are, of course, defective in that, until re-set, they are incapable of recording a second earthquake. But they possess a compensating advantage in the accuracy with which it is possible to time the occurrence of a shock.

Clock-stopping Apparatus.—As it is possible to make with ease, and at little cost, an extremely delicate apparatus for stopping a clock at the moment of a shock, I quote the following description of one devised by Prof. J. Milne (Japan Seism. Soc. Trans., vol. iii. pp. 61–62):—"P is the pendulum of a clock with a small piece of wire standing out at right angles to its face. . . . This wire, as the pendulum swings, passes beneath a series of teeth cut in a strip of wood lightly hinged at A and terminating at the other end, B, with a piece of stiff wire. If such a contrivance is allowed to fall, the teeth catch on the projecting pin of the pendulum, and it may arrest it at any portion of its swing." The arrangement which, at the time of an earthquake, allows the toothed lever to fall "consists of a piece of stiff wire, W, on which, near to one end, is a small cylinder of lead, L. The short end of this wire is pointed, and rests on a pivot-hole made in the head of a drawing-pin pressed into the side of the clock-case, S. To prevent this wire from falling, it is held up by a small silk thread, T, fastened to a second drawing-pin. As suspended, it is very unstable, and, instead of remaining at right angles to the clock-case, it swings round against it. When, however, the wire, B, rests on the end of W, it retains its position, as shown in the figure."



This instrument is so sensitive that it is difficult even to shut the clock-case without stopping the clock. The reason of this appears to be "that, if the clock-case receives a small displacement at right angles to W, the weight remains steady by its inertia, whilst the long arm of W in contact with B multiplies the initial motion" approximately in the proportion of the length of the long to that of the short arm of W.

It would appear that a displacement parallel to the wire W would not give this multiplication; but, practically, Mr. Milne observes, "it seems impossible to give a motion in that direction to which the apparatus does not seem to be just as sensible as to a motion in any other direction. The only other motion which does not result in stopping the clocks appears to be a *very slow* easy swing;" and thus the instrument will probably be incapable of recording the occurrence of the dying-out vibrations of a very distant shock.

The instrument may be placed in a cellar or out-house, or out of doors under the cover of a close-fitting box. A strong stake should be driven into the ground, to the depth of two or three feet, the floor, if any, being removed for a few inches round the stake to prevent the instrument being disturbed by the vibrations of the house. The clock-case should then be screwed firmly to the stake.

If several of these instruments are erected in a district, they should be placed at distances of not less than 5 to 10 miles apart.[1] The sites selected should, if possible, be free from the vibrations of passing carts and trains. If two or three of these record the occurrence of a shock at very nearly the same instant, it may be inferred that the disturbance is not accidental in its origin, and the inference will be strengthened if several instruments closely agree in their indications. But a record from one alone must obviously be regarded as doubtful, if all the others were at the time in good working order.

Suggestions for the Observation of Earthquakes (without the use of special instruments).—Lists of questions for aid in the study of earthquakes have been drawn up by Prof. Heim and Prof. Milne.[2] The following questions are founded partly on these lists, but chiefly on the accounts of earthquakes in different places, and especially in this country. It is hardly necessary to insist that all notes should be written down on the spot, or as soon after the shock as possible; but it may be useful to remark that it is often just as important to note when a given phenomenon is *not* observed as to describe it fully when it is observed. This applies particularly to the mere fact of the perception of the shock, as a knowledge of the places where it is just not felt is of service in enabling us to determine the boundary of the disturbed area.

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[1] A Committee of the British Association is at present considering the form of seismoscope most suitable for use in this country.

[1] If the clock be carefully rated, it should be possible to obtain the time of a shock correct to a tenth of a minute. The velocity of earth-waves is subject to wide variations, even in traversing the same rocks; but, taking it at 1000 feet per second, it follows that the earth-wave will pass over more than a mile in one-tenth of a minute. A good deal more than a mile, then, should separate every pair of stations where seismoscopes are placed.

[2] A. Heim, "Die Erdbeben und deren Beobachtung"; *Arch. des Sc. phys. et nat.*, 3me pér. t. iii. pp. 286–7; Fouqué, "Les Tremblements de Terre," pp. 133–4; Japan Seism. Soc. Trans., vol. i. part ii. pp. 3–4.

The questions are arranged in the following sections: A, for places where the shock is felt; B, for those where it is not felt; and C, inquiries to be made after the shock. In each case, the questions to which it is most important that answers should be given are marked with an asterisk.

A.—FOR PLACES WHERE THE EARTHQUAKE IS FELT.

1.—*Place of Observation.*

* (*a*) Its name and position.

(*b*) Nature and form of the surrounding ground, especially with reference to its geological structure and the neighbourhood of mountains, rivers, cliffs, &c.

2.—*Situation of Observer.*

* (*a*) Whether indoors or in the open air; if indoors, on which floor of the house.

(*b*) If indoors, the direction of the street or of the longer axis of the house (if detached).

* (*c*) How occupied at the moment of the shock—lying down, working, &c.

3.—*Time of Occurrence.*

* (*a*) Time at which the shock was felt; if possible to a tenth of a minute.

* (*b*) Is the time given the correct time obtained after comparison with an accurately rated chronometer? and, if so, how long after the shock was the comparison made, and how is the chronometer regulated?

4.—*Nature of Shock.*

* Describe the nature of the shock as closely as possible, stating especially: (*a*) the number of the more prominent vibrations; (*b*) their relative intensity; (*c*) whether there was any tremulous motion before or after the vibrations; (*d*) whether any vertical motion was perceptible; [(*e*) whether, in the latter case, the movement in the principal vibration was first upwards and then downwards, or *vice versâ*].

5.—*Duration of Shock.*

* Total duration, exclusive of that of the sound phenomena (stating whether estimated, or determined by watch).

6.—*Intensity of Shock.*

* Was the shock strong enough (*a*) to make windows, doors, fire-irons, or crockery, &c., rattle; (*b*) to cause the chair or bed on which you were resting to be perceptibly raised or moved; (*c*) to make chandeliers, pictures, &c., swing, or to stop clocks; (*d*) to overthrow ornaments, vases, &c., or cause plaster to fall from the ceiling; (*e*) to throw down chimneys or make cracks in the walls of buildings?

7.—*Direction of Shock.*

(*a*) Direction of the principal shock or shocks.

(*b*) Means by which the direction was ascertained.

(*c*) Was any change of direction perceptible during the earthquake?

8.—*Sound-Phenomena.*

* (*a*) If any rumbling sound was heard at the time of the shock, what did it resemble?

[* (*b*) Did the sound end abruptly, or die away gradually?

* (*c*) Did the sound become deeper or higher towards the end?]

* (*d*) Did it precede, accompany, or follow the shock? (Times useful, especially the intervals between the beginning of the shock and of the sound, and between the ending of the same; stating whether estimated, or determined by a watch.)

* (*e*) Duration (given by 5*a* and 8*b*, if not determined separately).

9.—*Effect on the Water of Ponds, &c.*

Were any movements observed in the water of ponds, rivers, lakes, or the sea, at, or shortly after, the time of the shock; if so, of what kind?

Accessory Shocks.

* Were there any slight shocks preceding or following the principal shock or shocks? If so, a list of these, with the place of observation, time of occurrence, and answers to any of the above questions, would be of great value.

B.—FOR PLACES WHERE THE EARTHQUAKE IS NOT FELT.[1]

1.—*Place of Observation.*

* (*a*) Its name and position.

* (*b*) Nature and form of the surrounding ground, especially with reference to its geological structure and the neighbourhood of mountains, rivers, cliffs, &c.

2.—*Situation of Observer.*

* (*a*) Whether indoors or in the open air; if indoors, on which floor of the house.

* (*b*) How occupied at the moment of the shock—lying down, working, &c.

C.—INQUIRIES TO BE MADE AFTER THE SHOCK.

1.—*Damage to Buildings.*

(*a*) Nature of the building damaged.

(*b*) Situation to the building, direction of its longer axis; neighbourhood to the edge of a cliff or bank, and on which side of this it lies; nature of the rock on which it rests.

(*c*) If any cracks formed, state in which walls; the direction and width of the cracks, and the points from which they start (sketches useful).

(*d*) If it is noticed that some walls are much damaged, while others at right angles to those are but little affected, what are the directions of these walls?

2.—*Rotation of Objects.*

* (*a*) If objects, such as chimneys, grave-stones, gate-pillars, &c., have been rotated on their bases during the shock, describe the initial and final positions of the objects (sketches useful); or state the direction and amount of the rotation (looking down on the object from above, is the direction the same as that in which the hands of a watch rotate, or opposite to that direction?).

(*b*) Is there any evidence of rotation in bodies with a circular base?

3.—*Effects on the Ground, Springs, &c.*

(*a*) Were any fissures or cracks formed in the ground? If so, state their length, width, depth, and direction, the nature of the ground in which they occur, and their relation to neighbouring cliffs, banks, &c.

(*b*) Was the height, quantity, or temperature of the water in springs affected by the shock?

4.—*Observations in Mines.*

If the earthquake was felt in a mining district, inquiries should be made as to the nature of the shock and of the sound-phenomena when observed by men in the mines; the depth of the workings in such cases, &c.

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[1] [The value of observations under this heading would be greatly increased if they are the result of numerous inquiries made in a district.]

5.—*Records of Self-registering Instruments.*

* An examination should be made of the records of self-registering instruments within or near the disturbed area—particularly of recording barometers, magnetic and tidal apparatus—with a view to determine the effects of the shock on these instruments, and also to ascertain by their means the exact time of occurrence.

While answers to any of the above questions would be useful in the study of an earthquake, especial pains should, if possible, be taken to determine accurately the time at which the principal shock occurs. Immediately it is felt, the time should be noted to the nearest second, and written down at once, a few seconds (to be ascertained by trial) being allowed for taking out the watch and reading off the time. As soon afterwards as possible, the watch used should be compared with an accurately regulated clock. But if this cannot be done, if the record cannot be relied on as correct to within a small fraction of a minute, a less close approximation cannot as a rule possess much value. The chief use of such a record is then to determine the epoch of the shock; and, in a matter of this kind, when two consecutive shocks in a given district may be separated by an interval of several years, a question of a few minutes, more or less, is of very little moment.

Next in importance to time-observations are those on the intensity of a shock. Without the aid of delicate instruments it is of course impossible to estimate the intensity with accuracy. But good results have been obtained by the use of a rough scale, according to which the intensity is determined by its effect on men and their dwellings. The following is the Rossi-Forel scale,[1] which is widely adopted by Italian and Swiss seismologists:—

Rossi-Forel Scale of Intensity.

I. Micro-seismometric shock: noted by a single seismograph, or by some seismographs of the same model, but not by several seismographs of different kinds; the shock felt by an experienced observer.

II. Extremely feeble shock: recorded by seismographs of different kinds; felt by a small number of persons at rest.

III. Very feeble shock: felt by several persons at rest; strong enough for the duration or the direction to be appreciable.

IV. Feeble shock: felt by persons in motion; disturbance of movable objects, doors, windows; cracking of ceilings.

V. Shock of moderate intensity: felt generally by everyone; disturbance of furniture and beds, ringing of some bells.

VI. Fairly strong shock: general awakening of those asleep; general ringing of bells, oscillation of chandeliers, stopping of clocks; visible disturbance of trees and shrubs; some startled persons leave their dwellings.

VII. Strong shock: overthrow of movable objects; fall of plaster; ringing of church bells; general panic, without damage to buildings.

VIII. Very strong shock: fall of chimneys, cracks in the walls of buildings.

IX. Extremely strong shock: partial or total destruction of some buildings.

X. Shock of extreme intensity: great disasters, ruins; disturbance of strata; fissures in the earth's crust; rock-falls from mountains.

Results to be expected.—It may be useful, in conclusion, to point out some of the results we may expect to obtain from a systematic study of earthquakes in this country.

The mere indication of the occurrence of a shock felt at a given place on a given day is of service in the compilation of earthquake statistics, and will tend to give completeness to our seismic record. With the help of such a record we can study the laws of the periodicity and geographical distribution of earthquakes. The time is past for drawing up chronological tables of shocks felt over the whole earth; but the importance of making our records complete for a definite area of study is becoming more and more evident.

The accurate determination of the time of occurrence in different places is of the very highest importance. Such observations, if sufficiently numerous, will help us in investigating the position of the area which constitutes the epicentrum; the way in which the vibrations are propagated outwards from the epicentrum; the velocity of the earth-wave, and the laws according to which the velocity varies with the distance from the origin. A knowledge of the time will also determine the question of the coincidence of shocks in distant areas, separated by a region in which the shock is not felt at all, and of other phenomena which may seem to be more or less intimately connected with the earthquake.

By a study of the intensity in the different parts of the disturbed area, we are enabled to draw one or more isoseismal lines with a fair approach to accuracy. From the form of these lines we can ascertain the approximate position of the epicentrum; and, from the relative distances between consecutive pairs of such lines, we can determine the way in which the intensity decreases as the earth-wave radiates from the origin, and the relations of this decrease with the form and geological structure of the ground.

The chief point to which our researches at present tend is thus the discovery of the position of seismic foci. But our ultimate object is something higher than and beyond all this. With certain exceptions, the slightest earthquake that occurs must indicate the site and mark the epoch of a step in the process of terrestrial evolution. To determine the laws of seismic distribution in space and time would therefore be to discover, in part, the laws that regulate the development of the earth's great surface-features. The study of earthquakes is fascinating enough in itself, but it acquires a loftier significance when viewed in its wider relations; for through it we may press forward to the solution of the great problem of geology—the origin and growth of mountain-chains.

THE HORNED DINOSAURS OF THE UNITED STATES.

IN vol. xxviii. of NATURE (pp. 439 and 515), an account was given by Prof. Moseley of the magnificent skeletons of Iguanodons now mounted in the Brussels Museum of Natural History, which were at that time regarded as among the most remarkable of that extinct group of giant reptiles commonly known as Dinosaurs. Since that date, however, we have been gradually—thanks to the indefatigable labours of the transatlantic palæontologists—acquiring a fuller knowledge of the representatives of this curious group, of which the remains are preserved in such fine condition in the Secondary rocks of the United States Within the last few years, from the writings of Profs. Marsh and Cope—and more especially the excellent figures by which those of the former are illustrated—we have acquired so much information as to the form and structure of the gigantic Jurassic species belonging to the Sauropodous sub-order of the Dinosaurs—such as *Brontosaurus*—that we have begun to regard these extinct creatures as old friends (or should we rather say enemies?) and to flatter ourselves that our knowledge of the whole class is well nigh complete.

Recent discoveries in the topmost Cretaceous or Laramie deposits of North America have, however, brought to light the existence of a group of Dinosaurs, hitherto only very imperfectly known, which are remarkable, not only on

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[1] *Arch. des Sc. phys. et nat.*, 3me pèr. t. xi. pp. 148–149; Fouqué, "Les Tremblements de Terre," p. 22 (footnote); *Bull. del Vulc. ital.*, anno iv. (1877), pp. 39–40.